

SIEMENS



Mathieu Dutré - Application Specialist MBSE

Analysis and optimization of physical models for HIL simulation

Industry drivers for HIL simulation

Model Driven

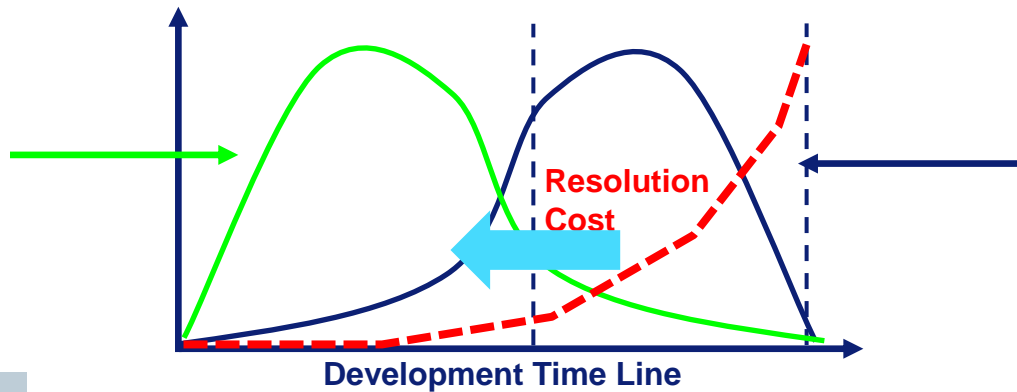


Virtual Design

Initial Prototypes Available

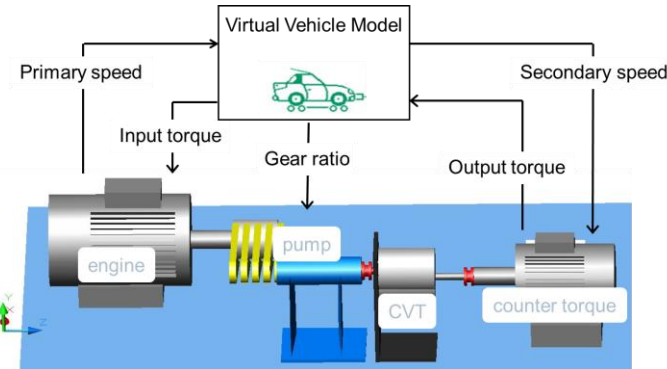
Production Ready

Prototype Driven



Generates usecases for HIL

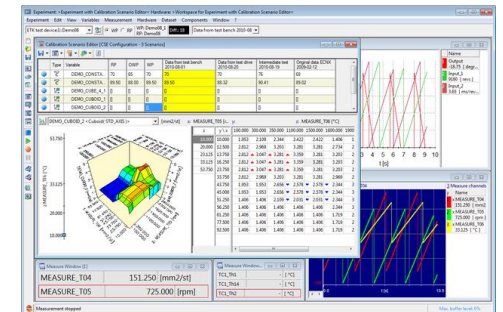
Frontload component testing



Driving Simulator



Controls calibration and validation



Why this session?

Prepare for HIL simulation

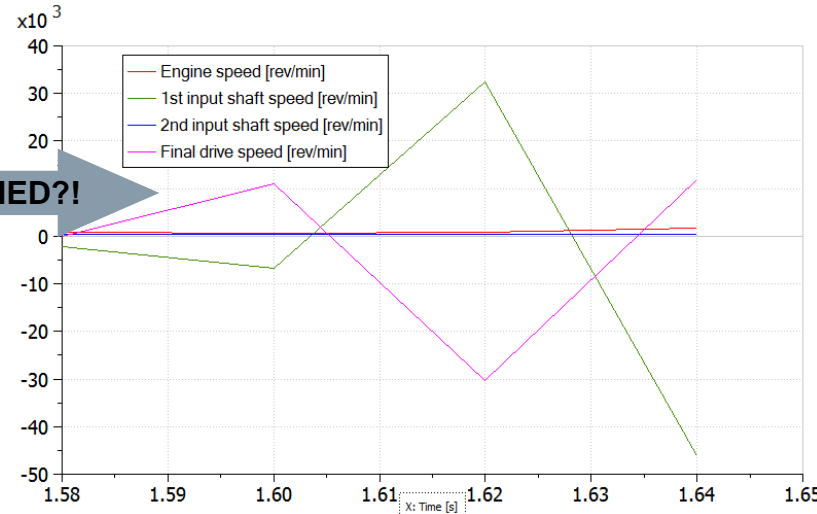
Virtual
Vehicle



INTEGRATION



?!PLANT MODEL CRASHED?!>

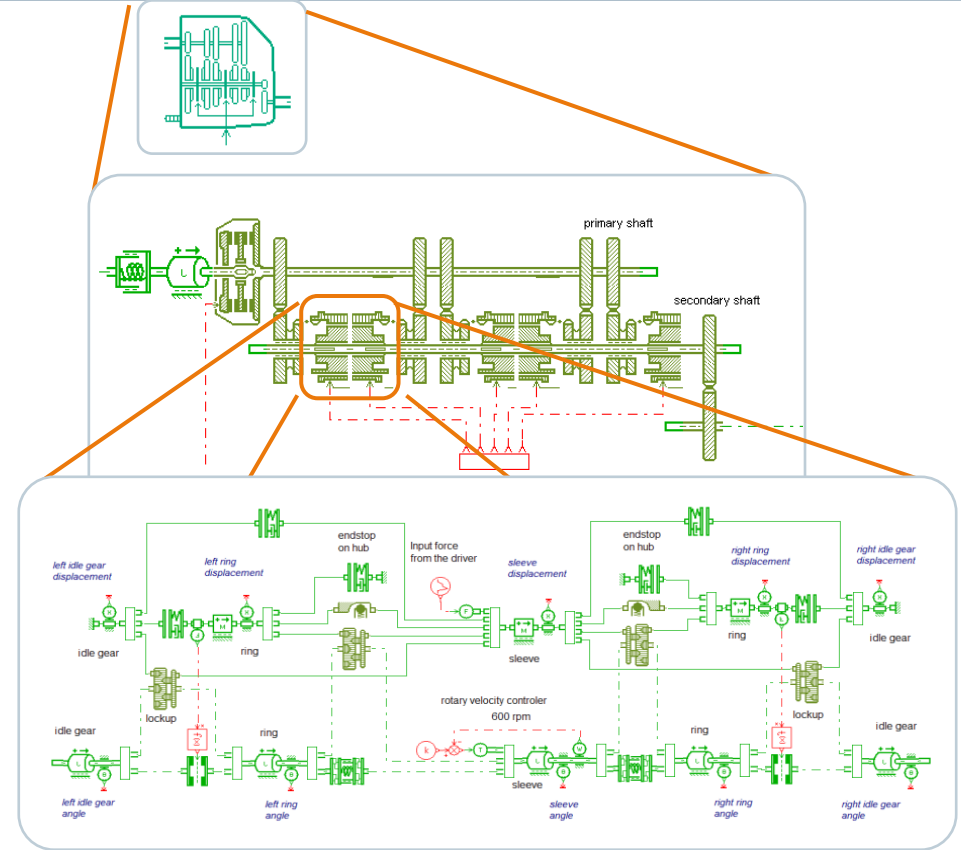
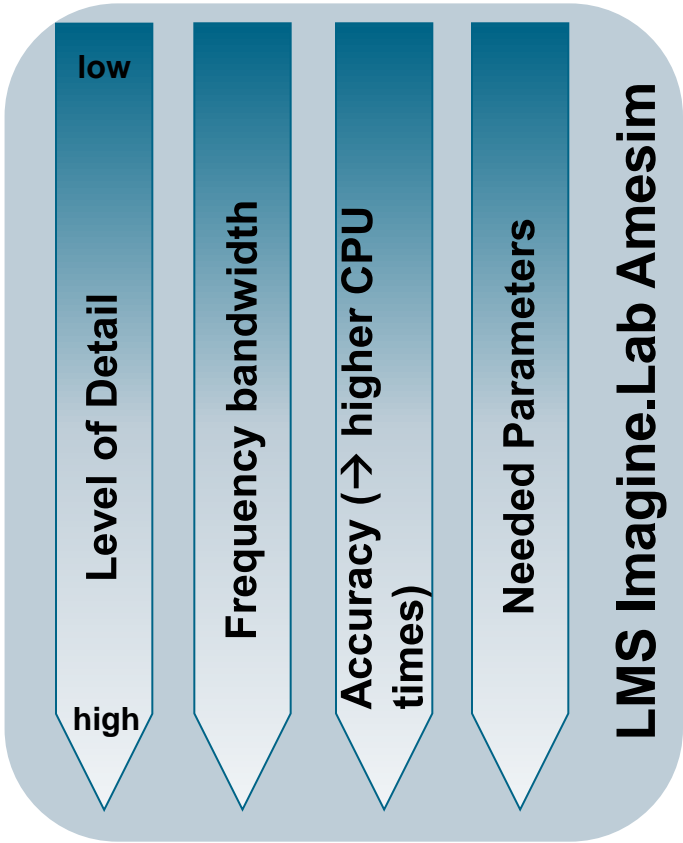


Provide support in the analysis and optimization of physical models prior to integration on an HIL system

- Understand reasons behind a “plant model crash”
- The different steps and need of model reduction techniques
- Connection between physical models and computer science
- Demonstration on the modal projection toolbox in context of HIL optimization
- Tricks to reduce the integration timestep requirements for your HIL platform

Selecting the right model using LMS Imagine.Lab Amesim

Prepare for HIL simulation



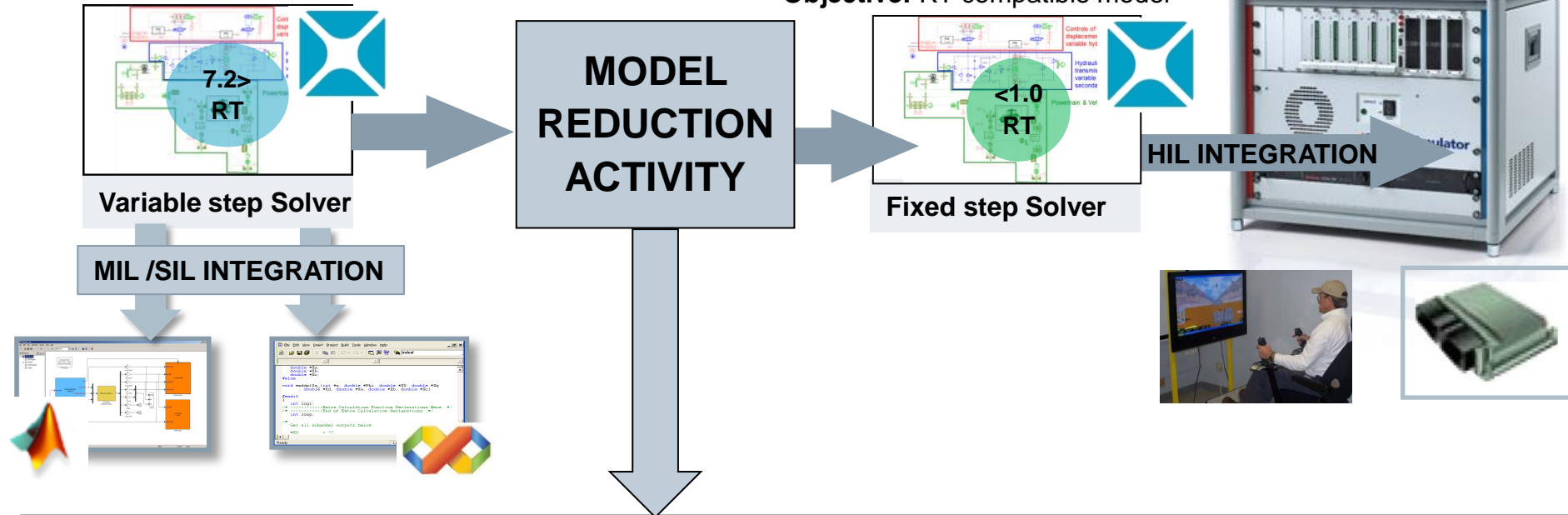
- The “proper model” is the one having the minimum complexity required to address the modeling objective (frequency range of interest)
- More details in your *.ame model, mean higher frequencies embedded in your model
- That could slow down CPU time in case these eigenvalues would be excited

Engineering questions prior to HIL integration

Prepare for HIL simulation

Starting point: High fidelity model for MIL/SIL

Objective: RT compatible model

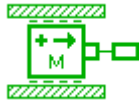


- What would be an appropriate sample time for my model on the for RT platform?
- Can I lower requirements of my sample time on the HIL platform by lowering my model fidelity or change parameters?
- What kind of physical component(s) is critical for the stepsize definition?
- What is the critical linearization time for the model?
- How to use my variable step solver model to analyze if my model is ready for a fixed step solver ?

How to connect physics to computer science?

Catch up with Systems Theory

Physical Models

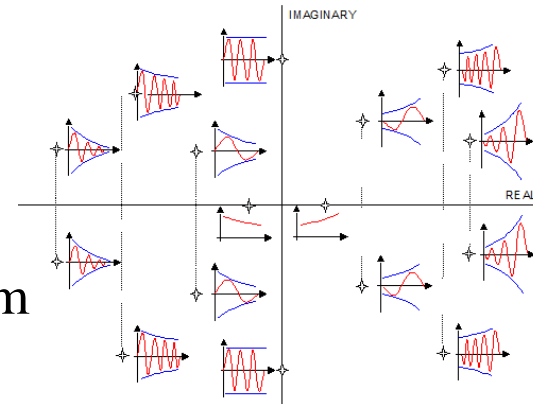


Differential equations

$$\begin{cases} \dot{\Delta x} = A \cdot \Delta x + B \cdot \Delta u \\ \Delta y = C \cdot \Delta x + D \cdot \Delta u \end{cases}$$

Eigenvalues

$$\lambda = \text{Re} \pm j \cdot \text{Im}$$



??

Requirements for solver used on the HIL platform?

Integration Methods – Solver stability criterium

Catch up with Systems Theory



SOLVE

$$\dot{x} = f(x, u)$$



EULER

Numerical integration (ODE1)

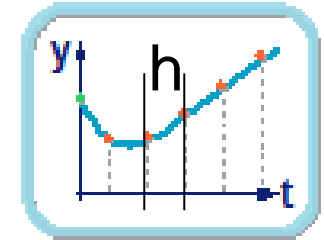
$$\frac{dx}{dt} \approx \frac{x_{n+1} - x_n}{h}$$

$$x_{n+1} = x_n + h \cdot f(x_n, u_n)$$

$$x_{n+1} = x_n + h \cdot \lambda \cdot x_n + h \cdot b \cdot u_n$$

$$x_{n+1} = (1 + h \cdot \lambda) \cdot x_n + h \cdot b \cdot u_n$$

[x_{n+1} is only a function of past values.
This is ok for real-time computation]



With $h = t_n - t_{n-1}$
(integration stepsize used on the RT platform)

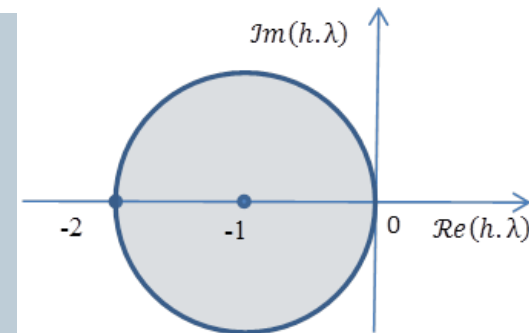
Assuming that the system is free ($u = 0$)

Stability criterium for ODE1 solver integration

$$x_{n+1} = (1 + h \cdot \lambda) \cdot x_n$$

$$x_{n+1} = a \cdot x_n \text{ Or } x_{n+1} = a^n \cdot x_0 \quad (\text{This equation converges only if } |a| < 1)$$

CRITERIUM for ODE1 INTEGRATION = $1 + h\lambda \leq 1$



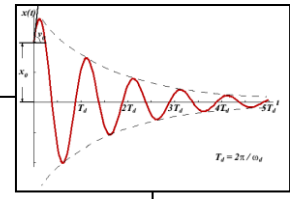
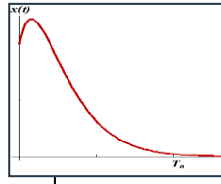
Connecting physics to computer science

Catch up with Systems Theory



$$F_{cpu} = \frac{1}{h}$$

CRITERIUM for ODE1 INTEGRATION = $1 + h\lambda \leq 1$
 $\lambda = Re \pm j.Im$



Faster system dynamics



Higher Eigenvalues



Thouger Requirements for RT solver

Overdamped: $\lambda = -R$

$$\left| 1 - \frac{R}{F_{cpu}} \right| \leq 1$$

$$-1 \leq 1 - \frac{R}{F_{cpu}} \leq 1$$

$$-2 \leq -\frac{R}{F_{cpu}} \leq 0$$

$$\frac{R}{2} \leq F_{cpu}$$

Oscillating: $\lambda = -R + j.I$

$$\left| 1 - \frac{R}{F_{cpu}} + j \cdot \frac{J}{F_{cpu}} \right| \leq 1$$

$$\left(1 - \frac{R}{F_{cpu}} \right)^2 + \left(\frac{J}{F_{cpu}} \right)^2 \leq 1$$

$$1 - 2 \frac{R}{F_{cpu}} + \left(\frac{R}{F_{cpu}} \right)^2 + \left(\frac{J}{F_{cpu}} \right)^2 \leq 1$$

[The natural pulsation : $W = \sqrt{R^2 + J^2}$]

$$\left(\frac{W}{F_{cpu}} \right)^2 \leq 2 \frac{R}{F_{cpu}}$$

$$\frac{W^2}{2R} \leq F_{cpu}$$

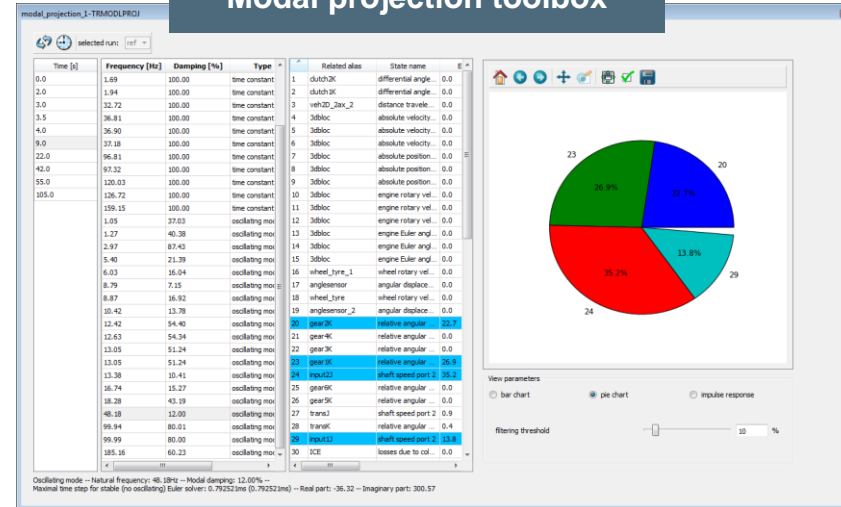
Tool for analysis & optimization of plant models for RT

Catch up with Systems Theory

How to do analysis for a complex physical system?

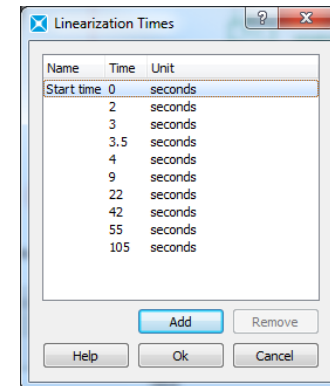
- Highlight the worst linearization time
- Highlight the worst frequency
- Highlight the majors State/variables/ components involved in each frequency
- Identify the correct maximum time step to use with Euler Solver (fixed step)
- Find variables by their names

Modal projection toolbox



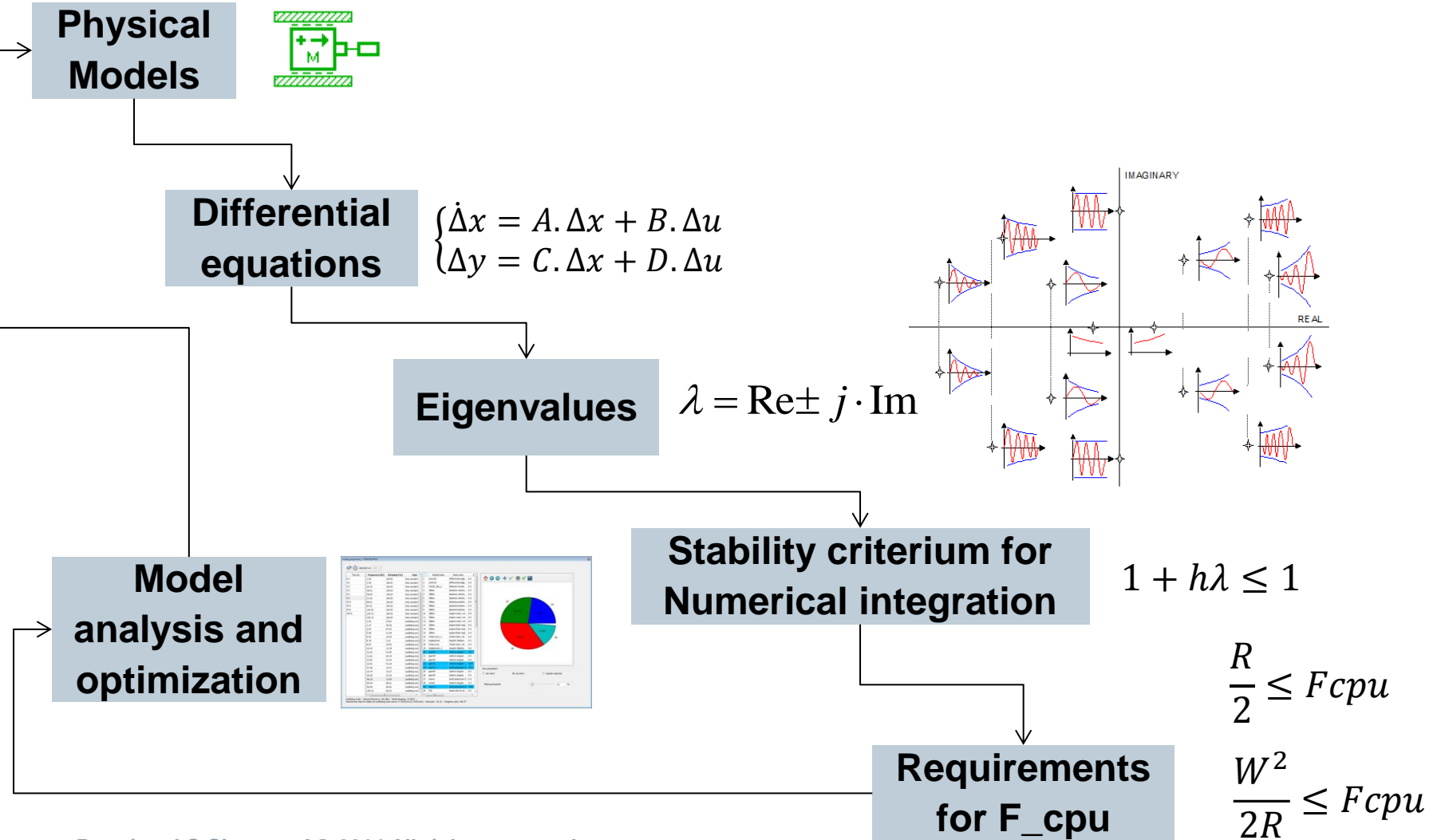
BENEFITS:

- ➔ Adapt your level of model easily and fast, tune the value of parameters
- ➔ Check that your simplified model is still providing accurate results



Model reduction workflow

Catch up with Systems Theory



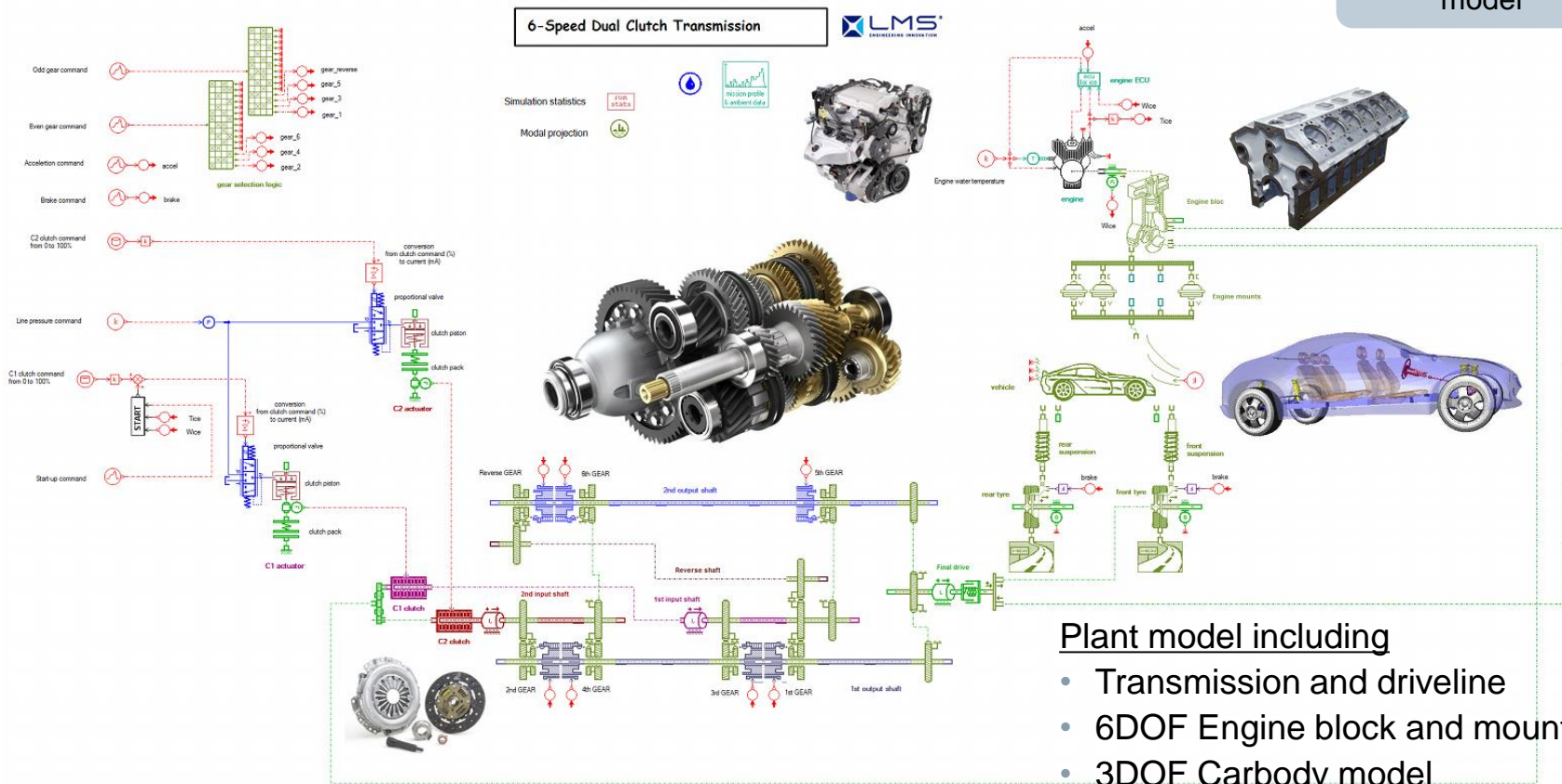
Starting point: a high fidelity model of the vehicle, its detailed transmission and actuators

Application example: Optimize a DCT model for HIL



Deploy the DCT model with a maximal integration timestep of 1 ms

DCT vehicle model



Plant model including

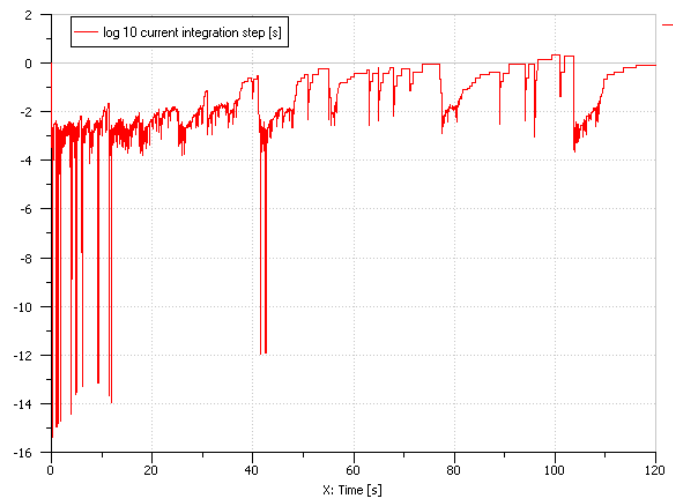
- Transmission and driveline
- 6DOF Engine block and mounts
- 3DOF Carbody model
- Transmission actuators

Analyze and reduce a detailed model for fixed time step solvers and Real Time simulations

DEMO

Application example: Optimize a DCT model for HIL

1) ANALYZE the integration timestep used by the variable step solver



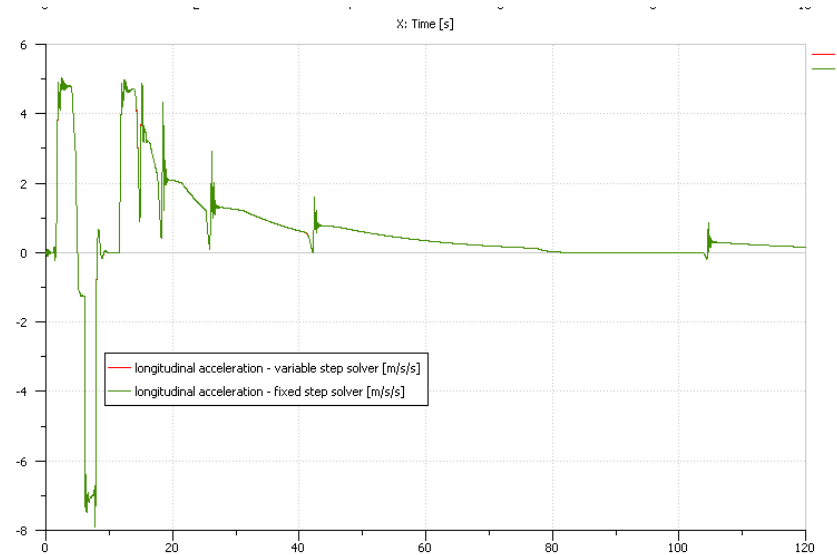
2) ADD linearization time for critical computation times

Name	Time	Unit
Start time	0	seconds
2	seconds	
3	seconds	
3.5	seconds	
4	seconds	
9	seconds	
22	seconds	
42	seconds	
55	seconds	
105	seconds	



3) ANALYZE and OPTIMIZE the physical components and parameters for fixed step solver requirements

4) EVALUATE impact of fixed solver on model correctness



Modal Projection Tool [modal_projection]

selected run: ref | Display time step info

Time [s]	frequency [Hz]	damping [%]	Ty	Related alias	State name	Ener
0.0	15.37	100.00	time cor	7	3dbloc absolute po...	0.0
2.0	22.47	100.00	time cor	8	3dbloc absolute po...	0.0
3.0	27.71	100.00	time cor	9	3dbloc absolute po...	0.0
3.5	27.91	100.00	time cor	10	3dbloc engine rota...	0.0
4.0	28.44	100.00	time cor	11	3dbloc engine rota...	0.0
9.0	98.24	100.00	time cor	12	3dbloc engine Eule...	0.0
22.0	98.70	100.00	time cor	13	3dbloc engine Eule...	0.0
42.0	121.08	100.00	time cor	14	3dbloc engine Eule...	0.0
55.0	127.62	100.00	time cor	15	3dbloc engine Eule...	0.0
105.0	159.15	100.00	time cor	16	gear2K relative an...	22.7
	1.06	35.73	oscillatr	17	gear3K relative an...	0.0
	1.28	40.12	oscillatr	18	gear1K relative an...	26.9
	3.55	88.32	oscillatr	19	input2J shaft speed...	35.2
	5.40	21.40	oscillatr	20	gear6K relative an...	0.0
	6.05	16.24	oscillatr	21	gear5K relative an...	0.0
	8.79	7.15	oscillatr	22	transJ shaft speed...	0.9
	8.85	17.48	oscillatr	23	transK relative an...	0.4
	10.46	13.59	oscillatr	24	input1J shaft speed...	13.8
	12.39	54.50	oscillatr	25	ICE losses due ...	0.0
	12.62	54.34	oscillatr	26	ICE BMEP dyna...	0.0
	13.05	51.24	oscillatr	27	ICE total fuel ...	0.0
	13.05	51.24	oscillatr	28	valve2 normalized...	0.0
	13.39	10.39	oscillatr	29	valve2 spool velocity	0.0
	16.78	15.04	oscillatr	30	piston2 displaceme...	0.0
	46.18	12.00	oscillatr	31	piston1 displaceme...	0.0
	99.93	80.01	oscillatr	32	valve1 normalized...	0.0
	99.99	80.00	oscillatr	33	valve1 spool velocity	0.0
	185.16	60.23	oscillatr	34	start_up.elec... output fro...	0.0

16 13.8 %

18 22.7 %

19 26.9 %

24 13.8 %

19 5.2 %

View parameters

view type: pie chart

filtering threshold: 10 %

C elem. I elem. U elem.

Oscillating mode -- Natural frequency: 48.18Hz -- Modal damping: 12.00% -- Maximal time step for stable (no oscillating) Euler solver: 0.792445ms (0.792445ms) -- Real part: -36.32 -- Imaginary part: 300.57

Typical changes towards HIL integration

Model reduction of a Hybrid Hydraulic vehicle

Plant Model: Citroën HYBRID AIR

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Place inertia sungear after reduction

replace clutch by variable reducer

Optimize the characteristics of the hydraulic valves

sum up inertia HP & sungear

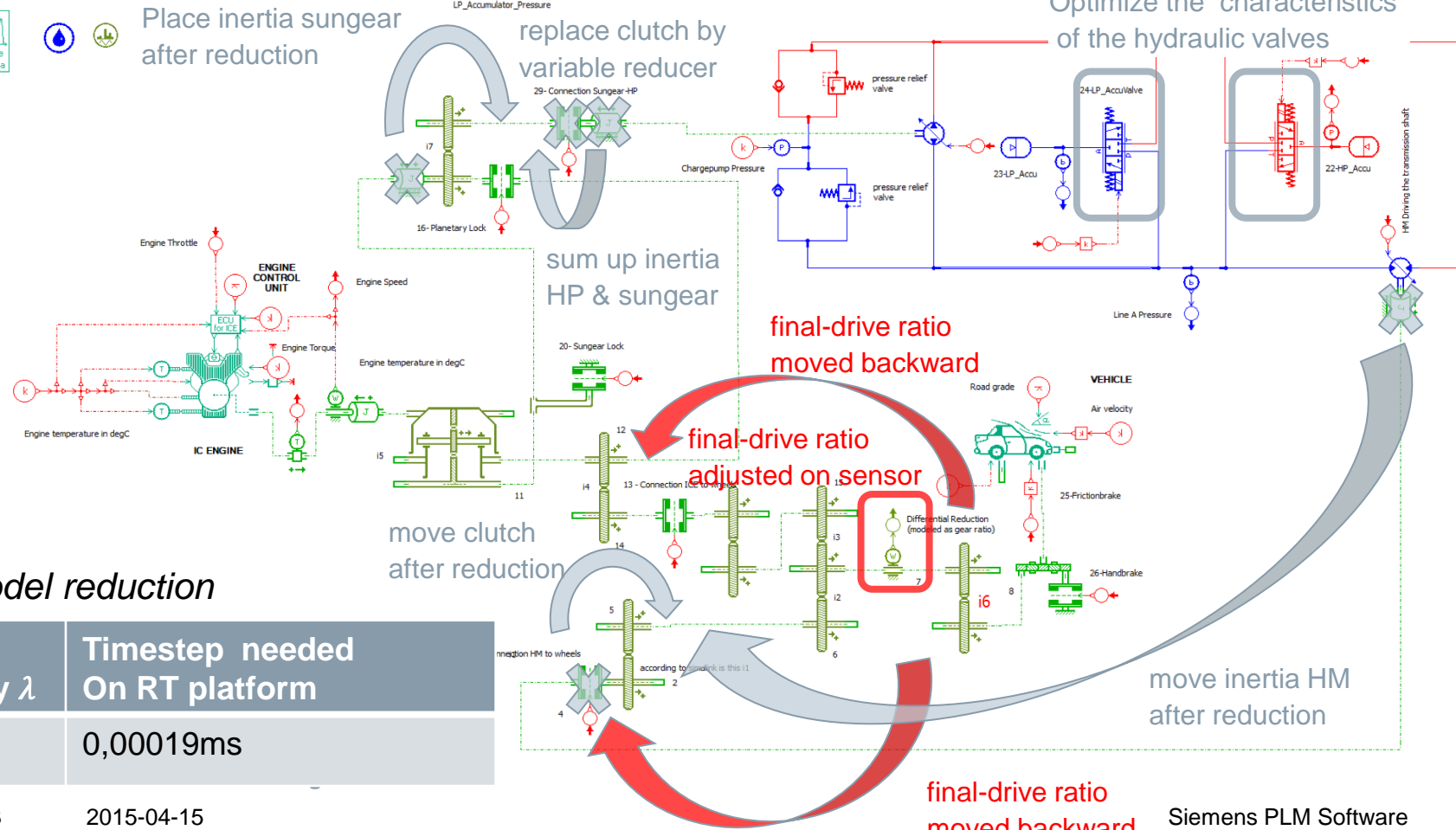
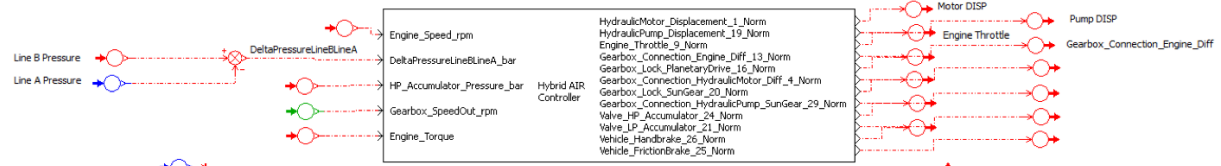
final-drive ratio moved backward

final-drive ratio adjusted on sensor

move clutch after reduction

move inertia HM after reduction

final-drive ratio moved backward



Before Model reduction

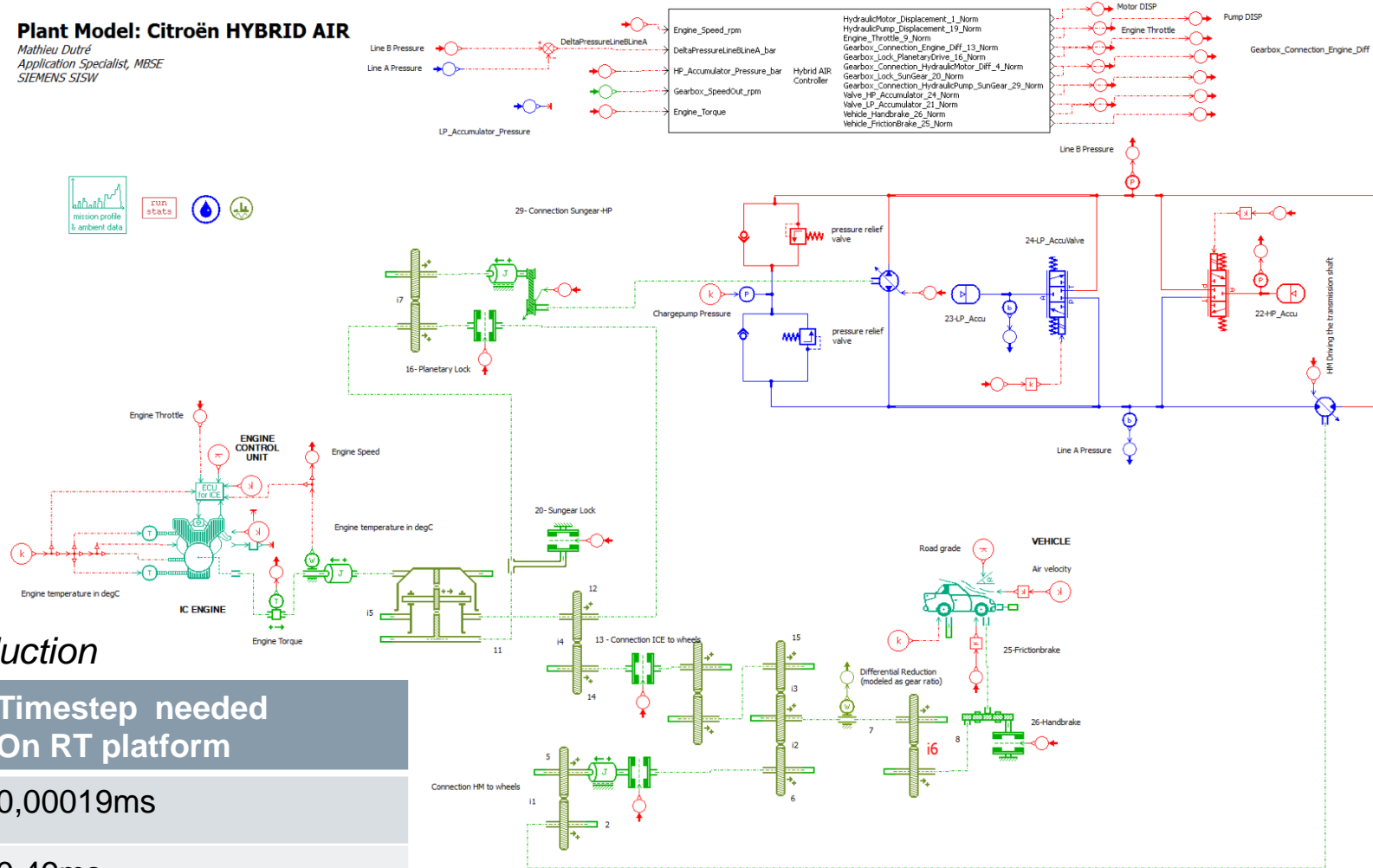
Natural Frequency λ	Timestep needed On RT platform
1.7MHz	0,00019ms

HIL compatible model

Model reduction of a Hybrid Hydraulic vehicle

Plant Model: Citroën HYBRID AIR

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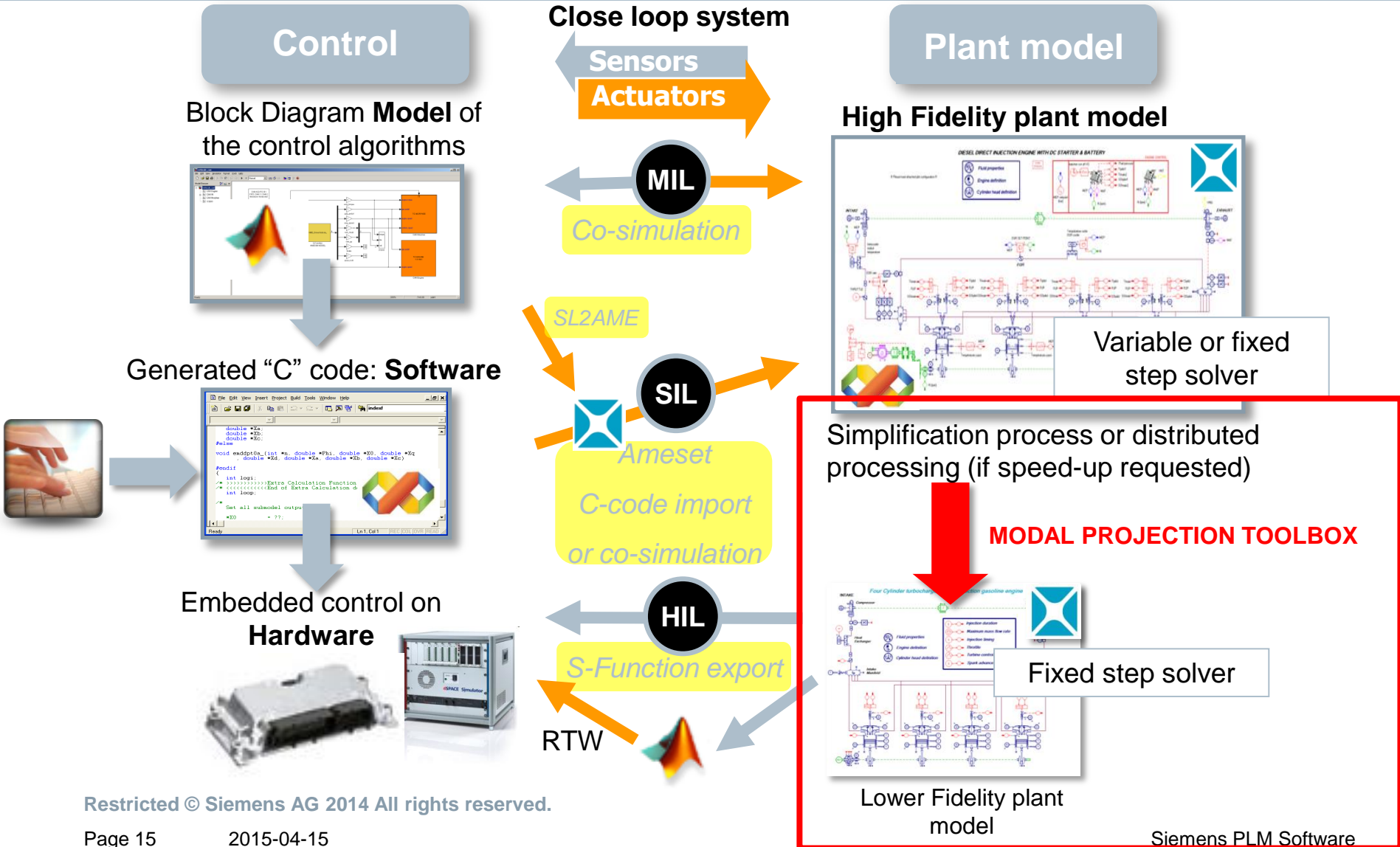


After Model reduction

Natural Frequency λ	Timestep needed On RT platform
1.7MHz	0,00019ms
655Hz	0,49ms

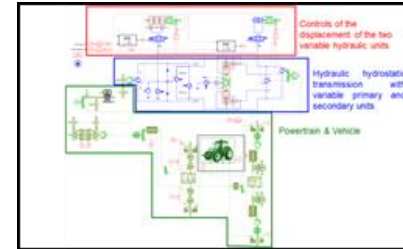
There's much more to say...

Siemens solutions for Solution setup for XiL

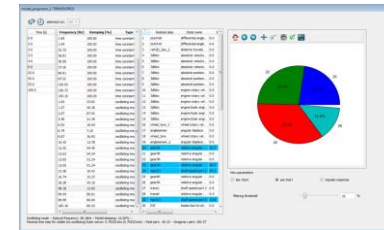


Summary

LMS Amesim: Platform to support you in physical modeling activities going from detailed component design to controls validation



Model reduction capability: Toolbox and process in place to support simplification of models towards HIL integration



Platform openness: Amesim allows HIL integration on a variety of HIL platforms



xPC Target

ETAS
Engineering Tools

AND
A&D Company Limited



Knowledge transfer: Siemens PLM has specialized engineering teams that can support you in your challenges related to xIL testing.

Thank you! Questions?

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